Joggins is a famous fossil locality in Nova Scotia, Canada. Hewn by some of the world’s highest tides on the Bay of Fundy, these crumbling cliffs shed light on the life and environments of the Carboniferous Coal Age, 315 million years ago. The site has been a magnet for geologists since the early nineteenth century. Charles Lyell described it as the world’s best coal-bearing section and together with his colleague, William Dawson, reported amazing fossil forests and a rich terrestrial fauna. Since that golden age, the rate of new fossil discoveries has hardly diminished and in recognition of its importance, the Joggins Fossil Cliffs was awarded UNESCO World Heritage Status in 2008. Even after many years of study, it remains a tremendous thrill for us to explore this ‘classic locality’ in far-flung Nova Scotia. Each winter storm, rock fall, and tide brings with it the tantalizing possibility of new fossils and new scientific insights. In this article we share something of our excitement for Joggins and provide an up to date field guide for those wishing to unlock its secrets.

Joggins is the place where time and tide meet. This remote site is located at the head of Chignecto Bay, one of the tidal inlets of the Bay of Fundy that almost divides Nova Scotia from New Brunswick in eastern Canada. At certain times of the year, tidal amplitude exceeds 12 metres on this restless coastline, making it home to some of the highest tides in the world. The origin of the peculiar name, Joggins, derives from the indigenous Mi’kmaq people. Since time immemorial, they have simply called the region, chegoggin—a place to fish—a reference to the shad fishery that once existed nearby. However, it was coal (not fish) that attracted early European settlers. Beginning in the 1680s, Joggins was one of the first places in North America where coal was mined, supplying fuel to burgeoning populations in Boston further south. The history of those early mines was turbulent to say the least, with Britain and France vying for control of these sought-after resources—all this against the backdrop of resistance from the Mi’kmaq, who retained mastery of Chignecto until the 1750s.

Geological exploration began at the dawn of the nineteenth century, and by 1835, Joggins was already well known. That year, it featured in the itinerary of an undergraduate fieldtrip out of Williams College, Massachusetts led by pioneering geologist, Ebenezer Emmons. Soon after, news of its coal and fossils reached the ears of Charles Lyell in London. While giving a lecture series in Boston, he squeezed in a short visit in 1842. Agog at the fossil forests he discovered there, Lyell eagerly wrote to his sister, describing them as the most wonderful phenomenon he’d ever seen. What particularly excited him was the fact that the trees proved that coal originated as a peaty soil beneath forests (not as logjams in rivers, as he had previously thought). A decade later, in 1852, Lyell returned to Joggins with Canadian geologist, William Dawson, and the two stumbled across a jumbled mass of bones within the hollow base of a fossil tree. These were identified as belonging to an early amphibian, *Dendrerpeton acadianum*. Over the next forty years, Dawson made further discoveries alone including the oldest known reptile in 1859, which he named *Hylonomus lyelli* after his mentor, and a rich invertebrate fauna. Lyell and Dawson’s work at Joggins exerted a huge impact on our perception of the Carboniferous Coal Age—and continues to do so today.

**Carboniferous coal age**

The Carboniferous is one of the most fascinating...
periods in Earth’s history—the subject of countless museum dioramas and TV documentaries. When the rocks at Joggins were deposited (315 million years ago), all the landmasses were joined together in a supercontinent called Pangaea and the tropics were covered by the early rainforests (Fig. 1). The compacted remains of this luxuriant vegetation are preserved as coal seams across present-day Europe and North America (Euramerica) so the Carboniferous is often referred to as the Coal Age. Recently one of us (HFL) has explored spectacular Coal Forests in underground mines in Illinois (see Geology Today, 2010, v25, pp.181–184) but the best-known Carboniferous forests occur at Joggins. The Coal Forests were quite unlike modern rainforests, made up of weird treesized clubmosses, horsetails and ferns. Animal life was dominated by scorpions, millipedes, cockroaches, spiders and dragonflies, so the Coal Forests would have been alive with buzzing and chirping.

During the Carboniferous Period, the Earth’s climate was rather cold and a large polar ice cap existed over the southern landmass called Gondwana. The best lines of evidence for this glaciation are the tillites found in South Africa and elsewhere in Gondwana, which lay near the South Pole, but another indicator can be found in the tropics. Here in Euramerica, which straddled the equator, rocks contain cyclothems (cyclic patterns of sedimentation) formed as sea level and climate fluctuated during repeated ice ages. During cool glacial phases when the ice cap was large, sea level dropped and the tropics dried out, forming continental drylands. As the ice melted during the next interglacial phase, sea level rose, climate humidified, and Coal Forests developed across the extensive wetlands that formed. This sea level rise continued until the Coal Forests were drowned under shallow seas. All of these three environments (drylands, wetlands and shallow seas) can be seen at Joggins. However, as the site was positioned so far inland compared to many other localities, seas were brackish rather than fully marine, freshened by rivers pouring into the basin.

One final noteworthy event that occurred during the Carboniferous Coal Age was the dramatic collision of Gondwana and Euramerica. This pushed up a great chain of mountains along the southern edge of Euramerica, the eroded remnant of which includes the Appalachians today. However, in eastern Canada, which was made up of a number of small crustal blocks, the collision had a different effect. In that region, some blocks were pushed up while others sank down. At Joggins, subsiding crustal blocks additionally squeezed a large body of halite (salt) locked in underlying strata. As this salt flowed up to the surface, its withdrawal at depth caused further subsidence. Thus, Joggins was one of the most rapidly subsiding places in the whole of Euramerica. As a result it preserves an unusually complete succession of coal-bearing rocks and fossils—an unrivalled window on the Carboniferous Coal Age. In fact the whole 915 m-thick classic section at Joggins was probably deposited in less than a million years—an amazing rate of accumulation.

Fig. 1. The Carboniferous World highlighting the location of Joggins (courtesy of Ron Blakey, Northern Arizona University).

Fig. 2. Satellite image showing the location of Joggins on Chignecto Bay captured on 30 April 2009 (courtesy of NASA). Inset map of eastern Canada.
The classic section at Joggins

If you’re following this guide to Joggins from the comfort of your sofa, note that throughout we’ll be using geographical co-ordinates taken from Google Earth to locate destinations, so why not point your browser at earth.google.com? For those truly intrepid explorers planning a visit in person, the easiest way to get to Joggins is via Halifax Airport, Nova Scotia (Fig. 2). From the airport, it’s a 2.5-hour drive along Highway 102 and 104 to Amherst (45°48′25.88″N; 64°12′00.83″W), the closest ‘big’ destination with hotels and restaurants. You then need to turn off the highway at Exit 4 and complete the final 30 km along quiet back roads that wind around the coastal flats. If you time your visit carefully, it’s worth pausing en route at the Tidal Wetlands Park at Maccan (45°42′59.86″N; 64°14′57.64″W) to catch a glimpse of the famous tidal bore. This phenomenon occurs about an hour before high tide as the waters of the Fundy are sloshed up the estuaries.

Arriving at Joggins around high tide, the best place to start is at the new interpretation centre (open late April–October) on the clifftop (45°41′44.37″N; 64°26′59.26″W). This innovative building was constructed to coincide with the award of UNESCO World Heritage Status on 7 July 2008—the culmination of ten years of preparation (see Geology Today 2004, v.20, pp.140–144). Its angled walls are designed to resemble bedding planes in the cliffs below and another feature is its green roof, solar panels and wind turbine to optimize sustainability (Fig. 3). A series of galleries provide excellent historical and geological context for the site, and a range of tours led by guides are offered. Nonetheless, experienced geological visitors will want to make their own journey, and we recommend exploring the cliffs beginning at Lower Cove, 2 km to the northeast (45°43′03.81″N; 64°26′02.75″W), and walking ‘up section’ to the UNESCO centre. At Lower Cove a convenient place to park is near the bridge over Little River (Fig. 4). Before commencing, it is important to stress that Joggins is protected under provincial law and fossil collecting is prohibited without a permit. Also note that rock falls are commonplace (it is unwise to linger beneath the cliff) and it’s safest to explore the section on a falling tide. You can comfortably access the section about 1.5 hours after high tide (Fig. 5).

Although the lowermost beds of the Joggins Formation have not yielded abundant fossils, visitors may want to ‘get their eye in’ by examining these rocks, where they form accessible low cliffs (45°42′44.13″N; 64°26′06.20″W). The base of the formation is marked by a coal only a few centimeters thick—you will have to look closely to observe this thin bed and its grey floor or ‘underclay’. As you walk southwest, you will notice thick red mudstones interrupted by thin layers of sandstone and siltstone. These ‘red beds’ were laid down by floods that brimmed over the banks of river channels and swept sediment across the adjoining plains. The fills of the channels themselves are visible as layers of resistant sandstone several metres thick, with irregular bases where the dryland rivers cut down into their floodplains. One of these channel fills, ~10 m above the base of the Joggins Formation, has yielded shells of Dendropupa vetusta, a small snail that was discovered by Lyell and Dawson and remains to this day the world’s oldest known land snail. In 1860, Bishop Sam Wilberforce referred to this hapless invertebrate as ‘miserable little Dendropupa’ in his stinging review of Darwin’s Origin of Species.

As you continue your exploration of Joggins, you...
will pass repeated cycles of red strata and grey beds with coal and limestone. These cyclothems record fluctuations between drylands, wetlands and seas. This was something that Lyell and Dawson well understood. Their profound insight—remarkable for its time—was that Joggins could be seen as a succession of ancient landscapes reminiscent of modern tropical deltas, inland river plains and shallow seas. As already alluded to, cyclothems may represent the deposits of glacial-interglacial cycles, although at Joggins it is hard to be sure because the climate signal is obscured by the high rate of accumulation. Nonetheless, this chequered history of rapidly changing environments is a hallmark of the Joggins Fossil Cliffs. The four main ‘stops’ highlight these different environments and draw attention to localities with particularly memorable fossils.

1. The Hebert Beds (drylands)
Continuing your journey farther south, one of the first sites of special interest is a reddish brown sandstone layer known as the ‘Hebert Beds’ (45°42′25.49″N; 64°26′16.82″W). The importance of this interval was recognized as recently as 1999, amply demonstrating how coastal erosion is constantly bringing to light new discoveries. That year, local teenager, Brian Hebert made some quite extraordinary fossil discoveries. Near the base of one sandstone ledge, he found a gigantic shell, close to a foot-long. This was the remains of a rare freshwater bivalve called *Archanodon westoni* (Fig. 6), the first specimen of this species to be discovered at Joggins since 1892. Other amateur collectors might have been satisfied with this prize, but Brian was no casual enthusiast. Since finding his first fossil as a 16-year-old, he determined to make a complete census of the Joggins fossil record—and hunted down arcane publications in dusty journals to identify his discoveries. In a matter of weeks, he had pulled a further ten specimens of *Archanodon* from the sandstone ledge, quickly followed by lots of early land snails, *Dendropupa*, and the bones of early amphibians!

Brian’s sandstone ledge occurs ~290 m above the base of the Joggins Formation, and forms a modest headland at the base of the cliff. The ledge became so synonymous with his fossil discoveries that ever since it has simply been known as the ‘Hebert Beds’. This fossil assemblage, which occurs in a thick red bed interval, sheds important light on the ecology of continental drylands at Joggins. The sandstone body contains the deposits of a network of small river channels. However, an unusual feature is the occurrence of raindrop prints and mud cracks close to the floor of the channels, suggesting that the rivers periodically dried up during seasonal droughts. The amphibians that Brian found may have assembled around shrinking bodies of water ponded in these dry channels in much that same way that watering holes attract animals in the drylands of East Africa or central Australia today. The gigantic *Archanodon* bivalves may have lain dormant in the mud on the channel bottom awaiting the next rainy season.

2. The Fundy Forest (wetlands)
Evidence for a rather different fossil ecosystem is found a little further southwest along the coast, where the Fundy Coal Seam crops out on the shore (45°42′13.72″N; 64°26′33.00″W). This site, which lies ~420 m above the base of the Joggins Formation, is very easy to locate. It is marked by a large number of timber pit props that protrude out of the cliff, the remains of late nineteenth century coal mine workings that have since become exposed to the elements through coastal erosion (Fig. 7). On most days, groundwater pours out of an old adit at beach level, draining the collapsed tunnels and laying down an orange deposit of ochre (iron oxides and hydroxides). Of especial interest at this site is the occurrence of numerous upright fossil trees in the beds below the coal seam. Once exposed, each tree survives for about...
three years before a combination of storms, tides and rockfalls erodes it away. Lyell spotted this fossil-rich interval during his whistle-stop tour of 1842, but of course all the trees that he documented have long since fallen into the sea.

The most prominent fossil trees are about 50 cm in diameter and superficially resemble fluted Roman columns. At any one time as many as fifteen trees have been observed at this interval, but numbers vary year by year. Only the lowermost two to three metres of the trunks are usually preserved, but commonly roots extend for many metres from the stump base (Fig. 8). These fossils are remains of giant club-moss trees, such as *Sigillaria*, which comprised wetland rainforests during more humid climatic phases. Their trunks were responsible, in large part, for forming the coal seams that occur throughout this rock interval. Other trees present include *Calamites*, giant ancestors of the modern day horsetail, which is seen rooted in dense thickets. Intriguingly, upright trees often show deep hollows around their base, infilled with sandstone. This shows that the wetland forests were regularly disturbed by powerful floods, which uprooted some trees and scoured around the base of others, burying them in sandy deposits. In fact trees are always preserved as sediment casts, formed as stems were snapped off and hollow interiors filled with coarse detritus.

Over the past twenty years, an important terrestrial fauna has been collected from the fossil forests below the Fundy Coal. In 1987, researchers from the Redpath Museum of McGill University, Montreal visited the site. (McGill has a long-standing connection with Joggins because Dawson was an early influential principal from 1855–1893). They picked up an ironstone nodule on the beach near the Fundy Coal Seam, which when prepared revealed a skeleton of the amphibian, *Dendrerpeton acadianum*—a much more complete specimen than that found by Lyell and Dawson in 1853. More recently, abundant trackways of amphibians and reptiles have also been discovered in these beds including the footprint of an enigmatic animal, reconstructed to have been up to two metres long. Affectionately known as ‘Rex’, this lumbering amphibian would have been one of the largest land animals in the Joggins ecosystem. Other spectacular fossil finds include whip spiders, millipedes, scorpions and ‘dragonflies’. Some of these discoveries were made by Don Reid, known as the ‘Keeper of the Cliffs’, an avid collector and past coal-miner who has been searching for fossils at Joggins for over 60 years! You will see many of Don’s finds in the interpretive gallery at the UNESCO Centre.

### 3. The Forty Brine (brackish seas)

Moving further southwest along the coast, two shelly limestone beds, up to a metre thick, occur on the foreshore, just above the Forty Brine Coal Seam (45°42’02.07″N; 64°26’58.03″W). These dark bituminous shell beds are positioned ~550 m above the base of the Joggins Formation and are worth close examination. They contain an abundant aquatic fauna, which tells us much about the ecosystems that existed when shallow seas flooded the Joggins area. Benjamin Lincoln, a young Harvard medical student, who explored the cliffs in 1829, was the first to note these fossils, and Dawson and Lyell later made more extensive collections. The fauna includes bivalves, ostracodes, sea scorpions (eurypterids), horseshoe crabs, and ‘shrimps’. In addition, a diverse assemblage of rays, sharks and bony fish has been uncovered. These fish remains were particularly sought-after by Don Baird of Princeton University, assisted by Harry Burke, who ran a fossil shop at Joggins in the 1960s and 70s.

This aquatic fauna together with horseshoe crab tracks (Fig. 9) and microscopic tests of foraminifera found a little higher in section at 570 m have been the subject of intense debate in recent years. Strata
at Joggins were long believed to have been lain down within an inland basin, entirely cut off from the sea, the limestone beds being deposited in large freshwater lakes. However, the fauna in the Forty Brine interval strongly suggests that water was at least brackish and therefore connected to open seas to the east, albeit distantly. The most compelling evidence for marine connection includes the bivalve, *Curvirimula*, which is closely associated with marine bands in the British Coal Measures. As sea level rose during deglaciation events on Gondwana, seas flooded across the British Isles, and eventually transgressed into eastern Canada where they lapped up against the Appalachians. However, within the narrow network of basins far inland, seas were freshened by rivers flowing into them. We envisage that the brackish seas of Joggins were, in some ways, similar to those of the Baltic Sea today.

### 4. Coal Mine Point (tree stump fauna)

The final stop in our guide is the site for which Joggins is especially famous. Near the southwestern end of the classic section, a 15 m-thick sandstone body occurs, which protrudes far out into the bay. Locals call this headland Coal Mine Point in memory of the pithead that was positioned on the clifftop a little to the south in the early twentieth century. Viewed from above, this sandstone shows a series of ridges and swales, indicating that it was deposited in a large meandering river channel that flowed across the Joggins wetlands. Just below this lies a thin sandstone bed, known as the ‘lower reef’, containing numerous *Calamites* and more upright *Sigillaria* trees (45°41′55.94″N; 64°27′03.71″W), somewhat similar to the Fundy Forests. It was within the broken remains of a tree that had fallen out of this layer that Lyell and Dawson made their now world-famous discovery of early amphibians. Notebooks at the Lyell Family Estate in Scotland date the discovery to 6 September 1852.

Six years later, in 1859, Dawson returned to the same spot, discovering a second tree, more richly stored with animal remains than the first. This included the famous specimen he named *Hylonomus lyelli* (Fig. 10). Convinced that thorough examination would yield yet further skeletons, in 1876, Dawson began an intensive study of the ‘lower reef’. This work was aided by a £50 grant from the Royal Society in 1878, to buy explosives to expose more trees. Although a risky strategy, it paid off and an additional 23 trees were uncovered, many of which contained amphibians, reptiles, millipedes, scorpions, and land snails, amongst other animal remains. In 1895, Dawson made a final visit to Joggins (he died in 1899) discovering further fossil-rich trees much lower in the classic section at the level of the Forty Brine Coal Seam. Just over one hundred years after Dawson’s initial discovery of *Hylonomus lyelli*, Bob Carroll at the Redpath Museum, McGill, recognized that the animal was in fact a reptile (not an amphibian as previously thought), and thus the oldest known. Despite various contenders, *Hylonomus* retains this accolade to this day.

The circumstance by which the trees at Coal Mine Point came to be filled with amphibian and reptile skeletons has been much debated. Lyell was very keen on what has subsequently been coined the ‘Pitfall Theory’. In this hypothesis, the fossil trees were partly buried in sand and rotted away to form hollow cylinders into which the hapless animals tumbled, never to re-emerge. However, careful comparison of the strata inside and surrounding the trees shows that the animals must have entered the trees prior to their burial, and some may have lived in or occasionally occupied the hollow stumps. In addition, the Pitfall Theory fails to explain the consistent occurrence of fossil charcoal (the residue of ancient wildfires) associated with the
bones in many trees—a fact highlighted by Lyell. One tantalizing possibility is that the animals used the hollow stumps as refuges from forest fires, only to be overcome by the conflagration! During the Carboniferous, the atmosphere was charged with more oxygen than at present, so fires would have burned especially fiercely.

Final steps

From the ‘lower reef’, it is an easy walk of only a few hundred metres back to the UNESCO centre. On the way it is worth pausing to look at a large fallen block of sandstone on Coal Mine Point, which shows two parallel grooves about a foot apart. These are tracks made by the passage of a giant arthropod called *Arthropleura*—an animal that resembled the woodlouse but attained a length of nearly two metres! Crossing to the south side of a small stream called Bell’s Brook (45°41′47.05″N; 64°27′01.06″W), a line of timber props are evident, driven into the wave-cut platform and passing from the cliff to the low water mark. These are all that remains of a great wharf that existed until the early twentieth century and allowed ships to be safely loaded with coal during high tide. A little further beyond, a set of permanent wooden steps lead back up the high cliffs to the UNESCO centre perched on top. After a quick coffee and bite to eat at the café, you can either retrace your steps, or walk back along the road to Lower Cove—a round trip of about 7 km. Of course, if you have two vehicles in your party, a much easier option is to leave one car at the UNESCO centre, cutting the distance walked by half!

We hope you have enjoyed this brief tour of Joggins. It is a truly special place—an extraordinary time capsule, preserving a faithful record of Earth’s tropical ecosystems, 315 million years ago. Despite walking this wild and remote shore for many years, there remains a tremendous thrill for us to return to Joggins, the fossil site where so many groundbreaking fossil discoveries have been made. As Dawson well understood, the richness of this amazing section may only be appreciated through study over a long period of time. More than 180 years after the first geologists walked these cliffs, perhaps what we have learnt most of all is just how much more remains to be discovered. Each winter storm, rock fall, and tide brings with it the exciting possibility of new fossils and new scientific insights. This has recently been underlined by the discovery of a nearly complete scorpion in 2009. Without any doubt, Joggins still has many secrets to reveal—and only time and tide will bring them to light.

Useful resources

The official website for the Joggins Fossil Cliffs contains a great deal of useful information: jogginsfossilcliffs.net

Case for UNESCO World Heritage Status: whc.unesco.org/en/list/1285/documents

A complete bed-by-bed log of the 915 m thick Joggins Formation, with a more complete scientific account of the cliff section, is available for free download here: journals.hil.unb.ca/index.php/ag/article/view/182/312.

Suggestions for further reading


